UNITED STATES PATENT APPLICATION FOR:

AN OPTICAL FIBER TRANSPORT METHOD AND APPARATUS FOR AN INTEGRATED OPTICAL FIBER PROCESSING SYSTEM

INVENTORS:

PHILLIP SOMMER
ALEXANDER BRUDNY

ATTORNEY DOCKET NO.: IPHO/0005.03

CERTIFICATION OF MAILING UNDER 37 C.F.R. 1.10

I hereby certify that this New Application and the documents referred to as enclosed therein are being deposited with the United States Postal Service on February 25, 2002, in an envelope marked as "Express Mail United States Postal Service", Mailing Label No. EV 041917596 US, addressed to: Assistant Commissioner for Patents, Box PATENT APPLICATION, Washington, D.C. 20231.

____
Signature

____
Name

____
Date of signature

PATENT
Attorney Docket No.: IPHO/0005.03
Express Mail No.: EV 041917596 US

AN OPTICAL FIBER TRANSPORT METHOD AND APPARATUS FOR AN INTEGRATED OPTICAL FIBER PROCESSING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation application under 37 C.F.R. § 1.53(b) of United States patent application serial number 10/038,093, filed January 4, 2002.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention generally relates to a method and apparatus for assembling optical subsystems or optical interconnections.

Background of the Related Art

[0003] In the manufacture of fiber optic communication systems, optical interconnects and other components are assembled to form various interconnected optical subsystems. Typically, optical components are integrated into optical subsystems that collectively create, for example, an optical switch. As the communication industry's need for optical communication bandwidth has increased, the ability for interconnect surfaces to provide a precise connection between optical subsystems is becoming critical, especially with regard to optical transmission modes that use multiple wavelengths of light to transmit information, such as Dense Wavelength Division Multiplexing (DWDM), for example. DWDM is a fiber-optic transmission technique that employs multiple light wavelengths to transmit data in a parallel-by-bit or serial-by-character format. DWDM is a major component of most optical networks that allows the transmission of e-mail, video, multimedia, data, voice—carried in Internet protocol (IP), asynchronous transfer mode (ATM), and synchronous optical network/synchronous digital hierarchy (SONET/SDH), respectively, over fiber optic communication systems.

[0004] Generally, fiber optic interconnections include two individual optical terminations mated together to provide a unitary and continuous optical path therethrough. Conventionally, to form an optical interconnect interface, fiber optic cables are terminated into an optical interconnection called a ferrule that is adapted to connect or mate the optical cables together. Ideally, optical interconnects, such as ferrules, are manufactured with precisely polished and dimensionally optimized

interconnect surfaces to provide low insertion loss and to prevent reflected transmission. Generally, optical interconnects are assembled in stages as subassemblies using a combination of a robotic assembly (*e.g.,* pick and place robotics) and/or by hand. Generally, as each assembly stage is finished, the subassemblies are stored as work in process (WIP) elements and/or pieces in a processing storage bin, awaiting the next process step. Unfortunately, optical components are often mishandled by assembly personnel and are often left in the process bin unprotected. Therefore, the conventional assembly processes often lead to incorrectly assembled or damaged optical components, which may lead to optical system performance and/or optical system interconnection issues. For example, a damaged or improperly assembled optical component may cause mechanical interface difficulties, poor specification repeatability, poor reliability, and undesirable interface aberrations, such as improper radius of curvature and apex offset, for example, which often affect insertion loss, light polarization, extinction ratio, return loss performance, etc. Moreover, staged subassembly processing systems are often inefficient, as the subassemblies often must wait long periods for the next process step requiring a larger than necessary WIP to maintain and adequate throughput.

[0005] Typically, interconnection inefficiencies are overcome by additional equipment, such as repeaters. Generally, repeaters amplify the optical signal to overcome insertion loss and signal attenuation, thereby extending the optical signal broadcast range. Additionally, testing equipment such as an interferometer may be used to precisely test, for example, the radius of curvature and apex offset. The radius of curvature is the radius of the interconnect surface, and is critical for proper mating of interconnect surfaces. The apex offset is the measure of the interconnect optical path alignment and is critical for the proper alignment of the optical paths between two optical interconnect surfaces. Unfortunately, as the optical subassemblies are assembled, the damage caused by the assembly processes must be accounted for and tested. Moreover, testing each interconnection and subassembly for parameters such as radius of curvature and apex offset increases the manufacturing time, and thus, the cost of the optical subassemblies. Further, for large fiber optic communication systems employing thousands of optical

interconnections, using equipment such as repeaters designed to overcome the interconnect inefficiencies may lead to an overall increase in the cost of the fiber optic communication system. Thus, having damaged or improperly assembled optical components affects the transmission of light, which affects information flow, reduces the system bandwidth, reduces the system efficiency, increases equipment costs, and generally increases the cost of the communication system.

[0006] Therefore, there is a need for a method and apparatus to provide a system for assembling optical components and subassemblies in a simple, repeatable, efficient, and cost effective manner.

SUMMARY OF THE INVENTION

[0007] Embodiments of the invention generally provide a method and apparatus for assembling optical components used in interconnecting optical subassemblies. In one embodiment, the invention provides one or more optical component processing stages for processing optical subassemblies, wherein the stages may include a component installation stage adapted to assemble a plurality of components on a plurality of fiber optic cables, a fiber preparation stage adapted to remove the outer coating of a fiber optic cable to expose a fiber optic cladding and core, and a component attachment stage adapted to attach at least one optical component on the cladding and the core. Additionally, a fiber trim stage adapted to trim an excess of cladding and core material from an optical interface, an optical surface polishing stage adapted to polish an optical interface surface, and at least one movable optical component carrier adapted to transport the plurality of fiber optic cables and the plurality of components between the one or more optical component processing stages may be provided.

[0008] Embodiments of the invention further provide an apparatus for transporting one or more optical components between a plurality of optical component processing stages of an assembly system. The carrier transport apparatus is generally adapted to move at least one optical component carrier between at least two optical component processing stages and position the at least one optical component carrier between a plurality of a processing positions with respect to each of the at least two optical component processing stages.

[0009] Embodiments of the invention further provide a system for transporting one or more optical components between a plurality of optical component processing stages. The system generally includes a conveyor system adapted to support at least one optical component carrier thereon, and a positioning system adapted to receive from the conveyor system the at least one optical component carrier, the positioning system being adapted to position the at least one optical component carrier between the conveyor system to a processing position with respect to the one or more of the plurality of optical component processing stages.

[0010] Embodiments of the invention further provide a method for transporting one or more optical components between a plurality of optical component processing stages. The method generally includes transporting at least one optical component carrier between at least two optical component processing stages on a conveyor, receiving the at least one optical component carrier at a positioning apparatus disposed along the conveyor, and positioning the at least one optical component carrier between the conveyor and a processing position with respect to one or more of the plurality of optical component processing stages with the positioning apparatus.

[0011] Embodiments of the invention further provide an optical assembly transport system for transporting one or more optical components stored within at least one optical component carrier traveling along a process path between a plurality of optical component processing stages. The system generally includes a frame and a plurality of rollers rotatably attached to an upper member of the frame, wherein the rollers are spaced and disposed along a longitudinal axis of the optical assembly transport system to support the at least one optical component carrier, and wherein each of the plurality of rollers are disposed about orthogonal to the at least one optical component carrier travel direction along the process path. Additionally, the system may also include a conveyor drive adapted to spin at least one set of the rollers to urge the optical component carrier upstream or downstream along the process path, and a carrier component positioning apparatus coupled to the frame and adapted to receive and position the optical component carrier for processing adjacent at least one of the plurality of optical component processing stages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that the manner in which the above recited features of the invention are obtained can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the embodiments thereof, which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention, and are therefore, not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0013] Figure 1 illustrates an exemplary simplified plan view of one embodiment of a staged optical component processing system of the invention.

[0014] Figure 2 illustrates a perspective view of an exemplary embodiment of an optical component carrier of the invention.

[0015] Figure 3 illustrates a magnified perspective view of the exemplary optical component carrier illustrated in Figure 2.

[0016] Figure 4 illustrates a perspective view of an exemplary component storage apparatus of the invention.

[0017] Figure 5 illustrates a plan view of an exemplary embodiment of an optical component attachment stage and an optical assembly transport system of Figure 1.

[0018] Figure 6 illustrates a side view of an exemplary embodiment of an optical component attachment assembly of Figure 5.

[0019] Figure 7 illustrates a front view of an exemplary embodiment of the component dispensing tube of Figure 5.

[0020] Figures 8A and 8B illustrate top and side views of an exemplary embodiment of a component feeder assembly of Figure 5.

[0021] Figure 9 illustrates a side view of an exemplary embodiment of component feeder assembly, and a sectional view of the lower end of the component dispensing tube assembly of Figure 5.

[0022] Figures 10A-10J illustrate partial sectional views of the operation of the component installation stage of Figure 5.

[0023] Figure 11 illustrates a perspective view of an exemplary embodiment of a fiber preparation stage of Figure 1.

[0024] Figure 12 illustrates a side view of the exemplary fiber preparation stage of Figure 11.

[0025] Figure 13A and 13B illustrate diagrammatic views of an exemplary embodiment of a stripping tool of Figure 11.

[0026] Figures 14A-F illustrate diagrammatic views of the operation of the fiber preparation stage of Figure 11.

[0027] Figure 15 illustrates a partial perspective view of an exemplary embodiment of a component attachment stage of Figure 1.

[0028] Figures 16-25 illustrate a top and side views of an exemplary embodiment of the component attachment stage of Figure 15 during a component attachment sequence.

[0029] Figure 26 illustrates a perspective view of an exemplary embodiment of an optical fiber trim stage and a polishing stage of Figure 1.

[0030] Figures 27 and 28 illustrate a perspective view and a side view, respectively, of the optic fiber trim stage of Figure 26.

[0031] Figure 29 illustrates a top view of the staged optical-subsystem polishing system of Figure 26.

[0032] Figure 30 illustrates a side view of an optical-subsystem polishing tool of Figure 26.

[0033] Figure 31 illustrates cut away perspective view of one embodiment of an optical-subsystem polishing tool of Figure 30.

[0034] Figure 32 illustrates a cut away side view of the optical-subsystem polishing tool of Figure 30.

[0035] Figure 33 illustrates a cut away side view of the optical-subsystem polishing tool of Figure 30 illustrating an optical component in a processing position.

[0036] Figure 34 illustrates a top view of an exemplary embodiment of an optical-component testing stage of Figure 1.

[0037] Figure 35 illustrates a side view of the optical-component testing stage of Figure 34.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0038] Aspects of the invention generally provide a method and apparatus for assembling optical components and optical subassemblies used in interconnecting optical systems. The term optical component herein generally refers to any component, assembly, or subassembly used in the manufacture of optical interconnects and optical subassembly. Figure 1 is a simplified plan view of one embodiment of a staged optical component processing system 100 of the invention. The staged optical component processing system 100 is a self-contained system having the necessary processing utilities supported on a system frame 101 that can be easily installed, and which provides a quick start up for operation. The optical component processing system 100 includes an optical component installation stage (CI) 102 adapted to install a plurality of optical components, *e.g.,* ferrules, onto a fiber optic cable. The term ferrule is used herein to denote a fiber-optic cable connector as is known in the art. Ferrules generally have three parts: a flange portion usually made of a rigid material, *e.g.*, stainless steel, to allow the ferrule to be mechanically coupled to an optical subassembly; a body; and a fiber optic cable receiving end having a small center opening used to receive a fiber optic cable (*i.e.,* pigtail) and an optical transmission portion to receive the cladding and core of the fiber optic cable. The body is typically made of materials such as zirconia, alumina, and materials similar thereto that may be adapted to support a fiber optic cable. Ferrule connectors are generally available in several different light transmission modes, such as single mode, which is used to transmit one signal per fiber, or multimode, which is used to transmit many signals per fiber, depending on the

number of wavelengths contained within the transmission. The optical component processing system 100 also includes an optical fiber preparation stage (FP) 104 adapted to remove an outer protective coating from a fiber optic cable to expose a fiber optic cladding layer surrounding a fiber optic core. The term core is used herein to describe the light transmission portion of a fiber optic cable, which is generally surrounded by the fiber optic cladding. The optical component processing system 100 further includes a component attachment stage (CA) 106, adapted to attach (*i.e.,* terminate) a component, *e.g.,* a ferrule, onto an exposed cladding and core portion of a fiber optic cable. To finish the component attachment and optical interface, the optical component processing system 100 may further include a fiber optic trim stage (FT) 108 adapted to cut and trim a fiber optic cladding and core length protruding from an optical component optical interface. The optical component processing system 100 may also includes an optical component interface polishing stage (POL) 110 configured to polish the optical interface. The optical component interface polishing stage (POL) 110 may include three polishing stages adapted to grind, polish, and finish the optical interface surface of the component in order to provide an exemplar optical interface connection. In one aspect, the optical component processing system 100 further includes an optical component testing stage (TEST) adapted to power (*i.e.*, bias), stimulate, and test optical component subassemblies for proper operation.

[0039] The optical component processing system 100 may further include an optical assembly transport system 114 configured to transport an optical component carrier 116 containing a plurality of optical components to be processed between optical component processing stages 102-111. The optical assembly transport system 114 may be adapted to support one or more optical component carriers 116 to allow for an efficient assembly process. For example, one optical component carrier 116 may be stationed adjacent the component installation stage 102 to receive optical components therein, while another optical component carrier 116 may be stationed adjacent the fiber preparation module 104 for fiber optic cable preparation. The optical component processing system 100 may also include a utility module 112, which houses the support utilities needed for operation of the optical component processing system 100, such as compressed air used to power

portions of the optical component processing system 100, de-ionized water and/or CO_2 used for cleaning, vacuum, and electrical power distribution components.

[0040] In one aspect of the invention, the optical component processing system 100 further includes a process controller 118. The process controller 118 is coupled to the optical component processing system 100 via an input/output (I/O) cable 90. In general, the processing system controller 118 may include a controller, such as programmable logic controller (PLC), computer, or other microprocessor-based controller. The process controller 118 may include a central processing unit (CPU) in electrical communication with a memory, wherein the memory may contain an optical component assembly control program that, when executed by the CPU, provides support for controlling the optical component processing system 100. In another aspect of the invention, the processing system controller 118 may provide control signals for the processing of the subassemblies at each processing stage 102-111, movement of the optical component carrier 116 on the optical assembly transport system 114, and optical component testing protocols at the testing stage 111. The processing system controller 118 may also be adapted to receive signals, such as processing status, test data, and the other signals from each of the processing stages 102-111, as well as the optical assembly transport system 114 to provide control of the component processing. The optical component assembly control program may conform to any one of a number of different programming languages. For example, the program code can be written in PLC code (*e.g.,* ladder logic), C, C++, BASIC, Pascal, or a number of other languages.

Optical Component Carrier

[0041] Figures 2-3 illustrate perspective views of one embodiment of an optical component carrier 116. The optical component carrier 116 is adapted to hold a plurality of fiber optic cables and optical components therein. The optical component carrier 116 includes a top 206 (*e.g.*, a lid), a bottom 214, a back wall 224, a front wall 210, and sidewalls 222 that define a storage region 200 therein. In one aspect, for ease of component loading and unloading, the lid 206 may be removable from, or hinged, to any of the sidewalls 222, the bottom 214, and/or the front wall 210. The optical component carrier 116 includes a front member 208 parallel to and disposed adjacent the front wall 210. The optical component carrier

116 also includes a mid member 209 generally orthogonal to the sidewall 222 and the bottom 214 and disposed between the front wall 210 and back wall 224. The mid member 209, sidewalls 222, and back wall 224, define an assembly holding region 226 configured to hold a plurality of component storage apparatuses 202 therein. The component storage apparatuses 202 may be adapted to hold a fiber optic cable and/or a plurality of components therein. The mid member 209 and front member 208 are separated by a plurality of partitions 218. The partitions 218 are generally parallel and spaced sufficiently from each other to hold a fiber or component therebetween. The partitions 218 are generally parallel to the sidewalls 222, and orthogonal to the front wall 210 and the bottom 214. The front member 208, the partitions 218, and the mid member 209 may be adapted to form individual component assembly slots 204 configured to hold a plurality of optical components and at least one fiber optic cable therein.

[0042] Figure 3 illustrates a magnified perspective view of the front member 208 and front wall 210, which are adapted to form a plurality of v-shaped notches 229, each of which may hold and position a fiber optic cable and/or optical component in a processing position. The front member 208 and front wall 210 are generally spaced apart to allow a clamp apparatus 230 to move freely in a vertical manner therebetween. The clamp apparatus 230 is generally adapted to hold a fiber optic cable or component, *e.g.,* ferrule, within the v-shaped notch 229. The clamp apparatus 230 includes a sliding member 232 that is slidably disposed between the front member 208 and front wall 210. The sliding member 232 includes a clamp member 236 that is adapted, when positioned against a component or fiber optic cable, to force the fiber optic cable or component into the v-shaped notch 229. The clamp apparatus 230 further includes an engaging member 234 coupled to the sliding member 232 to position the clamp member 236 toward or away from a fiber optic cable or component positioned within the v-shaped notch 229. The engaging member 234 is disposed within, and in sliding engagement with a slot 226 of the front wall 210. The slot 226 is adapted to allow a desired vertical travel of the sliding member 232 to release or engage the fiber optic cable or component within the v-shaped slot 229. While normally the weight of the clamp member 236 may be sufficient to supply a component holding force when a component is held between

the v-shaped notch 229 and the clamp member 236, in one aspect, the clamp apparatus 230 may be biased, *i.e.*, spring loaded, in order to provide a clamping force to the clamp member 236 to assist in positioning and holding the fiber optic cable or component within the v-shaped notch 229. In operation, a lifting tool or other engaging apparatus may activate the engaging member 234 to slide the sliding member 232 within the slot 226 to hold or release a fiber optic cable or component from the v-shaped notch 229. For example, as illustrated in Figure 3, an first engaging member 234' is positioned in a lower position in the first slot 226' to position the first sliding member 232' and first clamp member 236' to hold a first fiber optic cable 237 within a first v-shaped notch 229'.

[0043] Figure 4 illustrates a perspective view of one embodiment of a component storage apparatus 202. Each component storage apparatus 202 may include a c-shaped spool 247 adapted to support a fiber optic cable 237 thereon, and provide egress and ingress for a fiber optic cable portion therein for processing. The c-shaped spool 247 is generally adapted to dispense the fiber optic cable 237 from a spool opening 241 thereon. The c-shaped spool 247 may be made of a rigid material, such as metal, plastic, or other materials that are sufficiently strong and adapted to provide a suitable resilience for the fiber optic cable 237 wrapped thereon. The component storage apparatus 202 may further include two outer rings 242A-B that include outer walls 244A-B, respectively, to form a first cover 248A and a second cover 248B, respectively. The outer rings 242A-B may be made of any flexible material such as foam, rubber, and the like, adapted to provide resilience when compressed. In one aspect, the covers 248A-B, when placed in axial alignment and abutted, define an inner component void 245 and a fiber-dispensing slot 246 whereby the fiber optic cable 237 internal to the c-shaped spool 247 is clamped frictionally within the fiber-dispensing slot 246. In another aspect, the fiber optic cable 237 may be positioned within the inner void 245 in one or more loops to provide a strain relief as the fiber optic cable 237 is pulled in and out of the spool opening 241.

Component Installation

[0044] Figures 5 and 6 are a plan view and a side view respectively of one embodiment of the optical assembly transport system 114 and the component

installation stage 102. The optical assembly transport system 114 includes a plurality of rollers 302A-B. The rollers 302A-B are spaced and disposed along the longitudinal axis of the optical assembly transport system 114 to support the optical component carrier 116 and allow for ease of movement of the optical component carrier 116 between the processing stages 102-111. Each of the rollers 302A-B are rotatably mounted to the frame 101 and are generally disposed orthogonal to the travel direction of the optical component carrier 116. In one aspect of the invention, the optical assembly transport system 114 may include a conveyor drive 304 adapted to spin at least one set of the rollers 302A-B to engage the bottom 214 of the optical component carrier 116, and urge the optical component carrier 116 upstream or downstream along a process path defined by the optical assembly transport system 114. In one aspect, as illustrated in Figure 2, the conveyor drive 304 may include a conveyor motor 316 to drive a roller drive system 324 to rotate the rollers 302A-B. In another aspect, the optical assembly transport system 114 includes a carrier positioning apparatus 322 adapted to receive and position the optical component carrier 116 for processing. The carrier positioning apparatus 322 includes a shaft 325 coupled to a pedestal 323 adapted to support the optical component carrier 116. The pedestal 323 and shaft 325 extend through an opening 311 of the floor 319 of the optical assembly transport system 114 to engage the bottom 214 of the optical component carrier 116. The carrier positioning apparatus 322 may be adapted to move the shaft 325 and pedestal 323 generally in three dimensions, *i.e.*, parallel, vertical, and orthogonal, with respect to the longitudinal axis of the optical assembly transport system 114, *i.e.*, along the axis of rollers 302. In another aspect, the carrier positioning apparatus 322 may be coupled to the I/O cable 90 and responsive to the process controller 118 to position the optical component carrier 116 into a plurality of processing positions.

[0045] In operation, the optical component carrier 116 may be moved on the rollers 302A-B upstream or downstream along the optical assembly transport system 114. When the optical component carrier 116 is disposed about adjacent the position apparatus 322 the optical component carrier 116 may be stopped by at least two stop pins 308A and 308B. The carrier positioning apparatus 322 may raise the pedestal 323 upward to contact the bottom 214 of the optical component

carrier 116 and then lift the optical component carrier 116 off the rollers 302A-B to stop the optical component carrier 116 from moving to the next processing stage 102-111 and to position the optical component carrier 116 in a plurality of processing positions with respect to the component installation stage 102. Subsequently, the carrier positioning apparatus 322 may move the pedestal 323 and optical component carrier 116 to a desired processing position with respect to the component installation stage 102.

[0046] As illustrated in Figures 2-3, the component installation stage 102 may be mounted to the system frame 101 adjacent the optical assembly transport system 114 and may be adapted to insert components on fiber optic cables disposed within the optical component carrier 116. The component installation stage 102 generally includes a robot 310 adapted to retrieve and place components on a plurality of fiber optic cables disposed within the optical component carrier 116. A plurality of dispensing tube assemblies 320A-E (five are shown) are disposed on a table top 317 attached to frame 101, and are adapted to hold optical components and assembly components, such as retainers, springs, and other components, to be dispensed. The robot 310 is positioned at about the center of the component installation stage 102 and is adapted to retrieve the components from the dispensing tube assemblies 320A-E, and place the components on a fiber optic cable disposed within the carrier 116. In one aspect, the robot 310 includes a first arm 312 coupled at one end to an axial member 318 and a second end to a second arm 314 via a joint 316. The robot 310 includes a component transfer tool 331 rotatably mounted to a distal end of the second arm 314. The robot 310 and component transfer tool 331 are adapted to transport components from the dispensing tube assemblies 320A-E to the optical component carrier 116, and then install the components on one or more of the fiber optic cables therein. Once the components have been installed on the one or more of fiber optic cables, the optical component carrier 116 may be lowered by the carrier positioning apparatus 322 onto rollers 302A-B, which, in response to the conveyor drive 304 and rollers 302A-B (when activated), transports the optical component carrier 116 upstream or downstream to another processing stage 102-111.

[0047] Figure 7 illustrates one embodiment of a component dispensing tube assembly 320A. The component dispensing tube assembly 320A includes a plurality of component tubes 307. Each component tube 307 generally contains a plurality of vertically stacked components or subassemblies of the same type. For example, the component tubes 307 may contain stacked o-rings. While, the component tubes 307 are generally vertically aligned to facilitate the dispensing of the components through a dispensing orifice 309 using gravity, other alignments are contemplated. Alternatively, the component tubes may be placed configured to be spring biased in order to dispense components. The component tubes 307 are mounted to a component feeder assembly 330 adapted to facilitate the dispensing of components from the dispensing tubes 307.

[0048] Figures 8A and 8B are side and top views, respectively, of one embodiment of a component feeder assembly 330. The component feeder assembly 330 generally includes a nest plate 332 adapted to support the dispensing tube assemblies 320A-E, and component tubes 307. The component feeder assembly 330 may include a separator air actuator 334 adapted to move the nest plate 332 in a generally horizontal plane, and a pneumatic thruster 346 adapted to raise and lower the nest plate 332 to facilitate component dispensing. Figure 9 is a side view of the nest plate 332, the component transfer tool 331, including a component holding arm 337 and a sectional view of a lower end of the component dispensing tube assembly 320A. Figure 9 illustrates the pneumatic thruster 346 in a lowered position relative to the component dispensing tube assembly 320A and the component transfer tool 331 in a component holding position. The component transfer tool 331 includes on a distal end of the component holding arm 337, a component holding shaft 339 adapted to hold a plurality of components stacked in an axial position thereon. Illustratively, a plurality of components are shown stacked on the component holding shaft 339. In one aspect, the component transfer tool 331 may rotate the component holding shaft 339 between about a vertical component loading position and about a horizontal component dispensing position in about axial alignment with the longitudinal axis of the fiber optic cable to dispense components thereon. A dispensing tool 340 is disposed adjacent and in sliding engagement with the component feeder assembly 330. The dispensing tool 340 is

used to regulate the dispensing of the components through the dispensing orifice 309 and is actuated by a dispensing actuator 341.

[0049] Figures 10A through 10J are partial sectional views illustrating the operation of the nest plate 332, and component feeder assembly 330, dispensing components from the component tubes 307 onto the component holding shaft 339. Figure 10A illustrates a partial view of the component feeder assembly 330 in component acquisition position where the dispensing tool 340 and a separator 355 are shown in a retracted position relative a component 351A. To receive components therein, the nest plate 332 is disposed adjacent the dispensing orifice 309. Figure 10B illustrates a component groove 354 of the nest plate 332 having the component 351A dispensed therein. Figure 10C illustrates the separator 355 in a component separating position overlaying the component 351A. Figure 10D illustrates the dispensing tool 340 in a component holding position adjacent the next component 351B to hold the next component within the component tubes 307. Figure 10E illustrates the nest plate 332 in a lowered position. Figure 10F illustrates the holding shaft 339 extending through the nest plate 332 into an axial opening of the component 351A, to slide the component 351A thereon. Figure 10G illustrates the separator 355 in a open position to allow removal of the component 351A from the component groove 354. Figure 10H illustrates an empty nest plate 332 after the component has been removed by the component transfer tool 331. In one aspect, the component 351A is removed by the rotation of the component transfer tool 331 in a horizontal plane generally parallel the component groove 354. Figure 10I illustrates the nest plate 332 raised to a component loading position adjacent the dispensing orifice 309. Figure 10J illustrates the dispensing tool 340 and separator 355 in a retracted position to allow the loading of next component 351B into the component groove 354.

Fiber Preparation

[0050] Figures 11-12 are a perspective view and side view, respectively, of one embodiment of a fiber preparation stage 104 of Figure 1. Figures 11-12 illustrate the optical component carrier 116 in a pre-processing position. The fiber preparation stage 104 is disposed adjacent the optical assembly transport system 114 to receive a carrier 116 in a processing position. The fiber preparation stage

104 includes a fiber preparation tool 400. The fiber preparation tool 400 includes fiber strip/cut assembly 405, which includes an upper positioning member 414. The upper positioning member 414 includes a cutting tool 402 adapted to cut a fiber optic cable 237 and a stripping tool 404 adapted to strip the outer protective coating of the fiber optic cable 237 to expose the fiber optic cladding and core. The upper positioning member 414 further includes an upper positioning motor 418 adapted to move the cutting tool 402 to and from a cutting operation and the stripping tool 404 to and from a stripping operation. In one aspect, the upper positioning member 414 and upper positioning motor 418 may be controlled by the process controller 118 to position the cutting tool 402 and/or stripping tool 404 into a plurality of processing positions. The fiber preparation tool 400 further includes a lower positioning member 415 that includes a first gripper 416, and a second gripper 417. The first and second grippers 416,417 are adapted to hold the fiber optic cable 237 during a striping process or cutting processing step. The lower positioning member 415 includes a lower positioning motor 419 adapted to move the first and second grippers 416,417 between a plurality of processing positions. In one aspect, the lower positioning member 415 may be controlled by the process controller 118 to position the first gripper 416 and/or second gripper 417 into their respective processing positions.

[0051] In one embodiment, as illustrated in Figures 11-12, the optical assembly transport system 114 is configured as an indexing transport system 114'. The indexing transport system 114' includes a carrier support member 144 adapted to lift and hold an optical component carrier 116 between a component transport position and a component processing position. As illustrated in Figure 12, the indexing transport system 114' may also include a lifting apparatus 142 having a shaft member 147 in sliding engagement with the frame 101 via bearings 146. The shaft member 147 includes a rolling end 151 distal a support end coupled to the carrier support member 144. The rolling end 151 is in rotatable contact with a cam member 150 disposed on a camshaft 149. When rotated by a camshaft motor (not shown) the cam member 150 is adapted to raise and lower the shaft member 147 in a vertical direction from a lower cam position to an upper cam position, to urge the carrier support 144 into contact with the optical component carrier 116. In one

aspect, as illustrated in Figure 11, the indexing transport system 114' includes indexing stops 147A-C, adapted to index the optical component carrier 116 sequentially between a plurality processing positions with respect to the slots 204 therein. For example, if the optical component carrier includes ten slots 204, the indexing stops 147A-C may be adapted to sequentially position the optical component carrier 116 to ten processing positions corresponding to each slot 204. In operation, the indexing transport system 114' receives one of a plurality of optical component carriers 116 moving along the rollers 320A-B into a processing position relative the fiber preparation stage 104. A first stop 147B is raised vertically to contact recesses (not shown) in the bottom 214 of the optical component carrier 116, while the other two stops 147A and 147C are held in a lower release position. The first stop 147B contacts the optical component carrier 116, stopping the optical component carrier 116 in a first processing position. Subsequently, the camshaft 149 rotates to move the cam member 150 from a lower transport position to a raised processing position. In the raised processing position, the carrier support 144 lifts the optical component carrier 116 off the rollers 302A-B, and into a processing position. In one aspect, as illustrated in Figure 12, the carrier support 144 includes two support rails 152A-B where the support rail 152B includes a plurality of buttons 154 thereon, adapted to support a recessed portion (not shown) of the optical component carrier 116 bottom 214. In another aspect, a bottom gripper tool 153 is used to pull the bottom 214 of the optical component carrier 116 onto the buttons 154 to secure the optical component carrier 116 for processing.

[0052] When processing is finished at the first processing position, the carrier support member 144 is lowered into a release position, allowing the rollers 302A-B to contact the bottom 214 of the optical component carrier 116 thereby urging the optical component carrier 116 toward the next slot 204. Subsequently, the first stop pin 247B is lowered to a release position, and the outer two stops 247A, 247C are raised to a contact position with respective recesses (not shown) in the bottom 214 that correspond to the next slot 204 and second processing position. In one aspect, the fist stop 247B, and outer two stops 247A and 247C, alternate during processing to index the optical component carrier 116 along the optical transport system 114 in a sequential fashion. In another aspect of the invention, as illustrated in Figure 11,

the indexing transport system 114' includes an engaging tube 145 and an engaging tool 156 that are adapted to operate the engaging member 234 (see Figure 3) of the optical component carrier 116. Operational aspects of the fiber preparation tool 400 is described below with respect to Figures 13A-13B, and Figures 14A-14F.

[0053] Figures 13A and 13B illustrate one embodiment of a fiber stripping tool 404 in different operational positions. The fiber stripping tool 404 includes a body 421 having a first clamping member 422 juxtaposed to a second clamping member 423. The first and second clamping members 422-423 are disposed on, and in slidable engagement with a rail member 424 adapted to allow the first and second clamping members 422-423 to move between a plurality of fiber clamping positions. The first and second clamping members 422-423 are activated by a clamp drive 425 adapted to move the first and second clamp members 422-423 along the rail member 424. The stripping tool 404 further includes a first heating element 410A disposed on the first clamp member 422 and opposite a second heating element 410B disposed on the second clamp member 423. The first and second heating elements 410A-B are positioned to clamp a fiber optic cable 237 therebetween. The heating elements 410A-B may be of any conventional type, such as resistive heaters coupled to a power supply (not shown), that are adapted to heat, melt, and remove the outer protective coating from the fiber optic cable 237 to expose the cladding and core. Figure 13A illustrates the first and second clamp members in a non-clamping position about a fiber optic cable 237. Figure 13B illustrates the first and second clamp members 422-423 in a clamping position about the fiber optic cable 237. In one aspect, in order to maintain an even pressure along the clamped portion of the fiber optic cable 237, a first pin 427A and second pin 427B may be disposed along, distal the rail member 424, and in slideable engagement with a respective outer surface 426A-B of the first and second clamp members 422-423. In another aspect, to limit the travel of the clamp members 422-423 toward each other and establish a maximum clamping force, a third pin 428A and a fourth pin 428B may be disposed between and in slideable engagement with a respective inner surface 429A-B of the clamping members 422-423.

[0054] Figures 14A through 14F diagrammatic views illustrating one embodiment of a fiber preparation process for the fiber preparation stage 104 of Figures 11-12.

Figure 14A illustrates the first gripper 416 in position to pull the end of a fiber optic cable 237 from the optical component carrier 116. The first gripper 416 is positioned adjacent the optical component carrier 116 and a fiber optical cable 237 is illustrated protruding from the optical component carrier 116 and griped by the first gripper 416. Figure 14B illustrates the first gripper 416 gripping one end of the fiber optic cable 237 and the lower positioning member 415 moving the first gripper 416 about orthogonal away from the optical component carrier 116 to expose a portion of the fiber optic cable 237 for processing. Figure 14C illustrates the second gripper 417 holding the end of the fiber optic cable 237 to allow the first gripper 416 to reposition along the exposed fiber optic cable 237 toward the carrier 116 to expose a portion of the fiber optic cable 237 for processing therebetween. Subsequently, as illustrated in Figure 14D, the first gripper 416 moves to a second processing position where it grips the fiber optic cable 237 at a point along the exposed length of the fiber optic cable and the stripping tool 404 positions the first and second clamp members 422-423 about the exposed portion of the fiber optic cable 237. Subsequently, the first and second clamp members 422-423 and heating elements 410A-B are clamped around the fiber optic cable 237. Once the first and second clamp members 422-423 have clamped the fiber optic cable 237, the second gripper 417 moves away to a neutral position. As illustrated in Figure 14E, once the outer protective coating has been heated sufficiently to melt and be removed, the stripping tool 404 is moved laterally along the fiber optic cable 237 to remove the outer coating of the fiber optic cable 237 exposing the fiber optic core and cladding. Once the outer protective coating has been removed, the cutting tool 402 is positioned adjacent the first gripper 416 and cuts the fiber optic cable core. After cutting, the cutting tool 402 moves to neutral position as illustrated in Figure 14F. Although in one aspect, a first stripping process removes about 900 microns of fiber coating and a second stripping process removes about 400 micron or about 250 microns of outer protective coating, depending upon the coating thickness, the processes need not be done at the same process step. For example, the a first layer of the outer protective coating may be removed first, the fiber optic core cut by cutting tool 402 and then a second layer may be removed.

Component Attachment

[0055] Figure 15 is partial perspective view of one embodiment of a component attachment stage 106 adjacent the optical assembly transport system 114 wherein a plurality of components 538 have been attached to at least one of a plurality of fiber optic cables 237 extending from an optical component carrier 116. Figures 16-25 are a top and side views, respectively, of one embodiment of the component attachment stage 106, illustrating a component attachment sequence. As illustrated in Figure 15, the component attachment stage 106 may include a component attachment assembly 500 adapted to attach (*e.g.*, terminate) a component 538 onto a fiber optic cable. The component attachment assembly 500 includes a fiber gripper assembly 505 having a plurality of attachment pinchers 506 thereon. As illustrated in Figures 16-23, the component attachment assembly 500 may include an attachment robot 507 rotatably mounted to a robot platform 508. The attachment robot 507 may include an attachment gripper 503 thereon adapted to grab and move one or more fiber optic cables from the optical component carrier 116 into a processing position within each attachment pincher 506. As illustrated in Figure 15, the component attachment assembly 500 may further include a component attachment tool 510 that is adapted to hold one or more components 538, *e.g.*, ferrules, for attachment on the fiber optic cable. The component attachment tool 510 is rotatably mounted to a movable attachment assembly 512 that moves the component attachment tool 510 between a plurality of component loading and a component attachment positions. The moveable attachment assembly 512 may be driven by an attachment motor 522, such as a linear motor or stepper motor. In one aspect, the component attachment tool 510 may be rotated by a rotation motor 523, such as a linear motor or stepper motor, such that a plurality of component holding recesses 514 are positioned in a component loading position to accept components 538 therein. In another aspect, when loaded with components for an attachment process, the component attachment tool 510 may rotate to align a fiber-receiving end of the components 538 in an axial attachment position with respect to a longitudinal axis of the mating fiber optic cable 237.

[0056] In operation, as illustrated in Figures 16-25, the attachment robot 507 moves at least one of a plurality of fiber optic cables 237 from the optical component

carrier 116 into an attachment orientation with respect to a fiber-receiving end of a mating optical component 538. Subsequently, the attachment assembly 500 attaches at least one of a plurality of mating optical components 538 on one of the plurality of mating optical fibers 237. For example, as illustrated by Figures 16 and 17, optical fibers 237 are positioned by the attachment robot 507 into the fiber gripper assembly 505 within a respective attachment pincher 506 so that a length of the fiber optic cables 237 extend from a respective attachment pincher 506 (ten are shown). In one aspect, the optical fibers 237 are positioned so that an exposed fiber optic cladding and core length extends from the pinchers 506. In another aspect, as components 538 may have different axial insertion (*i.e.,* attachment) depths, therefore, the exposed fiber optic cladding and core length may extend according to the axial insertion depth. Thus, when inserted on the exposed fiber optic cladding and core length, a flange member of the components 538 are generally in axial alignment and may abut a respective pincher 506. Figures 18 and 19 illustrate the component attachment tool 510 including a first set of the plurality of components 538 after laterally moving into an attachment position with the fiber optic cable 237. The component attachment tool 510 is rotated to align the individual components 538 into about axial alignment with the exposed core of a mating fiber optic cable 237. In one aspect, the component attachment tool 510 includes a component rotation assembly 525 adapted to individually rotate the components 538 about their longitudinal axis to allow the optical fibers 237 to be more easily inserted.

[0057] In another aspect, the components 538 and/or the fiber optic cable 237 include epoxy therein to bond the fiber optic cable 237 to the mating component 538. Figures 20 and 21 illustrate the component attachment tool 510 moved into an attachment position by the movable attachment assembly 512. Figures 22 and 23 illustrate the components 538 after attachment. In one aspect, when epoxy is used, an epoxy curing apparatus 528 may be used to cure the epoxy. In another aspect, the epoxy curing apparatus 528 heats the attached components 538 and fibers 237 to cure the epoxy therebetween. Figures 15, 24, and 25 illustrate one type of epoxy curing apparatus 528 positioned by a positioning apparatus (not shown) in an epoxy-curing position including the components 538 therein. To facilitate a uniform

epoxy heat-curing process, the epoxy curing apparatus 528 may be adapted to clamp around the components 538 to impart heat more evenly.

[0058] As illustrated in Figures 15-25, to increase throughput, the component attachment tool 510, when rotated in an attachment position, may include an alternative component loading position where a plurality of secondary component holding recesses 514' are positioned vertically to accept components for a subsequent attachment process. Thus, when the attachment process is complete the component attachment tool 510 rotates to align the next set of components 538' for a subsequent attachment step.

Fiber Trim

[0059] Figure 26 is a perspective view of one embodiment of an optical fiber trim stage 108 and a polishing stage 110 of Figure 1. Figures 27 and 28 are a perspective view and a side view, respectively, of one embodiment of the optic fiber trim stage 108 adjacent the optical component transport system 114. The fiber trim stage 108 includes a laser-cutting tool 600 adapted to trim and cut the excess core and cladding of an exposed portion of a fiber optic cable extending from an optical component, *e.g.,* a ferrule, to develop a generally smooth optical interconnect surface. The laser-cutting tool 600 generally includes a laser source 602 and a laser splitter assembly 604 adapted to position one or more laser beams on a fiber optic cable. In one aspect, the laser source 602 may be any coherent laser light source adapted to burn away the fiber optic cable protruding from and adjacent an optical interface portion of the optical component. As illustrated in Figure 28, the laser splitter assembly 604 includes a first laser transmission path 605 coupled on one end to the laser source 602, and on another end to a splitter 606. The splitter 606 includes a first split transmission path 608 and a second transmission path 609 for guiding a first and second split laser beam 620 and 621 therein, respectively. The first and second split transmission paths 608-609 are coupled on a distal end to a first laser light positioning member 610. The laser light positioning member 610 is adapted to position the first and second split laser beams 620-621. In one aspect, the laser light positioning member 610 aligns one laser beam 620 about orthogonal to a protruding fiber optic cable and/or exposed cladding and core. In another aspect, the laser light positioning member 610 aligns the other laser beam 621

about axially with respect to the longitudinal axis of the fiber optic cable and/or exposed cladding and core.

[0060] The laser-cutting tool 600 may further include a trim positioning apparatus 614 moveably disposed on a frame member 611 and being adapted to hold and position a component 538 for processing. In one aspect, the component 538 is held by a trim pincher 616 disposed on the trim positioning apparatus 614. The trim positioning apparatus 614 may include a horizontal trim motor 618 and a vertical trim motor 619 adapted to move the trim pincher 616 vertically and horizontally between a plurality of processing positions. In operation, the trim positioning apparatus 614 moves a component 538 attached to a fiber optic cladding and core, from the optical component carrier 116, between a pre-process position to a trim process position. Subsequently, a protruding length of the fiber optic cladding and core extending from the surface of the component is trimmed (*e.g.*, burned) away from the surface of the optical component 538 by using the first and/or second laser beam 620-621.

Component Interface Polish

[0061] Figures 29-33 illustrate an exemplary embodiment of the staged optical-subsystem polishing system 110 of Figure 1, adjacent the optical assembly transport system 114. Figure 29 is a top view the staged optical-subsystem polishing system 110. The exemplary optical component polishing system 110 may generally include three polishing apparatuses 708 that provide three optical component polishing stages, which may be a coarse polishing stage 702 where optical components are given an initial coarse polish, a fine polishing stage 704 where optical components are given a finer polish than the initial coarse polish, and a finish polishing stage 706 where optical components are given a finish polish. The optical components are generally polished at each stage using a web of polishing material having a polishing surface thereon, that may be manufactured from materials such as silicon-carbide, diamonds, silicon-dioxide, and other polishing materials. In one aspect, after the coarse and fine polishing stages, the component is cleaned with de-ionized water. Subsequently, an inert pressurized gas, such as CO_2, for example, may be used as a cleaning agent to remove any fine residue adhering to the optical surfaces produced during the polishing process. The

polishing apparatus 708 may be used to polish the optical interconnect surfaces of optical components, *e.g.,* ferrules.

[0062] Figures 30-31 illustrate a side and perspective view, respectively, of a polishing apparatus 708 that may include a body 712, a support 718, and a mounting plate 715. Figure 29 may be referenced with the discussion of Figures 30-31. In one aspect, the body 712, support 718, frame 101, and mounting plate 715 are mounted to each other using conventional fasteners such as screws, bolts, nuts, and the like, and in another aspect may be a single component. While in another aspect, the support 718 is vertically mounted on the mounting plate 715 to define a vertical polishing position for an orbital assembly 720 to help in the removal of polishing debris, it is contemplated that the orbital assembly 720 may mounted in any position to perform the same polishing function. In one aspect, a collection tray 760 is disposed under the orbital assembly 720 to collect debris and fluids during processing. The tray 760 is coupled to a drain 761 that is fluidly coupled to a waste collection system or container (not shown).

[0063] As illustrated in Figures 29-30, the orbital assembly 720 includes a polishing assembly 730 and a spacer 732 flexibly coupled to the polishing assembly 730 and rigidly mounted to the support 718. The polishing assembly 730 is positioned to allow the optical component to be polished at generally an orthogonal direction relative the support 718. The polishing assembly 730 includes a right and left side plate 734,736, respectively, adapted to support a polishing table 738, a polishing material supply apparatus 740, and a polishing material receiver 742. In one aspect, the polishing table 738 is formed from a rigid material having a low coefficient of friction, such as Teflon ® impregnated aluminum, stainless steel, or other materials having a low friction surface thereon. In another aspect, the low friction surface may be applied to the polishing table 738 as a coating thereon. The polishing table 738 also includes a polishing surface recess 739 formed therein. In operation, a web of polishing material 765 is disposed over the polishing table 738 proximate the recess 739 and between the polishing material supplier 740 and polishing material receiver 742. Generally, the polishing table 738 is adapted to orbitally rotate within the polishing assembly 730 to polish optical component optical interfaces.

[0064] As illustrated in Figure 31, in one aspect, the polishing material supply apparatus 740 includes a brake 752 and is adapted to support a roll of polishing material 765 thereon (see Figure 30). The brake 752 applies a frictional force to the polishing material supply apparatus 740, which keeps the roll of polishing material 765 taught. The polishing material supply apparatus 740 further includes a supply clutch 754 to control the dispensing of the polishing material 765 from the polishing material supply apparatus 740. As illustrated in Figure 31, the polishing material receiver 742 is coupled to a receiver clutch 764 mounted to the left side plate 736. The receiver clutch 764 constrains the web of polishing material movement to only one direction from the polishing material supply apparatus 740 to the polishing material receiver 742. The polishing material receiver 742 is rotated by a drive apparatus 743 (see Figure 29) to take up and thereby advance the polishing material 765 across the polishing table 738. In one aspect, the supply clutch 754, drive apparatus 743, and brake 752 are operated together to control the advancement of the web of polishing material 765 while maintaining a taught web of polishing material 765 across the polishing table 738. As such, the polishing material 765 contacting optical components may be refreshed as needed via advancement of the polishing material from the supply apparatus 740 to the receiver 742.

[0065] Figures 32-33 are a partial cut away side view and side view respectively of one embodiment of the polishing assembly 730. Figures 29-31 may be referenced with the discussion of Figures 32-33. In one aspect, the polishing assembly 730 is coupled to an orbital actuator 770 to move the polishing table 738 in an orbital motion about a polishing plane that is generally orthogonal to the surface of the optical component being polished. The orbital actuator 770 includes a drive frame 780 supporting a motor 774 coupled to an eccentric shaft 776 extending generally perpendicular through the support 718. One end of the eccentric shaft 776 is rotatably coupled to the polishing table 738 via a bearing 772. One or more counter balances 778 are disposed on the eccentric shaft 776 to offset the centrifugal and centripetal forces developed by the non-uniform mass distribution of the polishing table 738 during operation, thereby minimizing vibration.

[0066] As the eccentric shaft 776 axially spins, it orbitally rotates about a motor shaft center 785. As the bearing 772 generally provides some rotational friction, the polishing table 738 is rotationally urged about the shaft 776 in the direction of the shaft rotation. To rotationally constrain the polishing table 738, while allowing the polishing table 738 to simultaneously move with the orbital rotation of the eccentric shaft 776, four flexible supports 750A-D are rotatably mounted on one end to the spacer 732 and on an opposite end to the polishing table 738. Thus, in operation, the polishing table 738 moves in an orbital fashion about the shaft 776 while maintaining a generally parallel position with respect to the support 718. In one aspect, to minimize the tension and allow for flexure of the polishing material and 765 during processing, a pair of rotatable strain relief members 783A and 783B are in rotatable engagement with the polishing material 765.

[0067] As illustrated in Figure 32, a component support 782, used to support optical components during processing, is mounted by a support 775 to a polishing force apparatus 744. The polishing force apparatus 744 is used to position and force optical components held by the component support 782 against the polishing material 765 (see Figure 33). The polishing force apparatus 744 may be any apparatus such as a motor driven actuator adapted to move the component support 782 generally perpendicular toward and away from the polishing table 738, and as needed, during a polishing operation, maintains pressure of the optical component against the polishing material 765. The polishing force apparatus 744 may be slidably mounted to a polishing position apparatus 746 which may be mounted to an upper end 722 of a secondary support 718 prime. The polishing position apparatus 746 may be any apparatus such as a motor driven actuator adapted to laterally move the component support 782 generally parallel to the polishing table 738 and across the surface of the polishing material 765. In one aspect, as illustrated in Figure 31, the component support 782 is independently secured to a secondary support 718' mounted to the frame 101 to provide vibration isolation from the polishing assembly 730. In another aspect, the polishing force apparatus 744 and polishing position apparatus 746 are mounted to the support 718, 718' via flexible mounting fasteners such as rubber, vinyl, plastic, nylon, and the like, adapted to provide vibration damping therebetween.

[0068] In one aspect, (see Figure 30) an air inlet/outlet 747 is disposed on the right side plate 734, in communication with the polishing table 738, and coupled to air conduction channels (not shown) that extend through the polishing table 738. The air conduction channels are coupled to a plurality of holes 751 (see Figure 32) disposed around the recess 739 within a groove 758. A vacuum pressure may be provided to the groove 758 via the air inlet/outlet 747 through the holes 751 to hold the web of polishing material 765 to the polishing table 738 during a polish process. In one aspect, the holes 751 may be distributed throughout the recess 739 and/or the groove 758 to allow the recess 739 under vacuum to hold the web of polishing material 765 to the polishing table 738. In another aspect, air pressure may be provided from the air inlet/outlet 747 to the holes 751 during a polish material cleaning/renewing process to force the polishing material 765 away from the polishing table 738 releasing debris and/or allowing the polishing material 765 to be dispensed from the polishing material supply apparatus 740 to the polishing material receiver 742.

[0069] In one aspect, the component support 782 further includes a sensor assembly 788, adapted to measure the polishing pressure of the optical component against the polishing material 765 during a polishing process and provide a signal to the process controller 118 indicative of the polishing pressure. In operation, the polishing force apparatus 744, sensor assembly 788, and process controller 118 form a polishing pressure feedback system to maintain a generally constant pressure between the optical component, polishing material 765, and the polishing table 738 throughout the polishing process.

[0070] In another aspect, as illustrated in Figure 32, a sub-pad 756 typically composed of a flexible material such as rubber, vinyl, resin, plastic, and other suitable flexible material, that provides a flexible, but firm, polishing surface, may be disposed in the recess 739. The sub-pad 756 is also adapted to provide a desired amount of flexure and resistance under the polishing material 765 against the component to form a desired radius of curvature for the optical surface being polished. In one aspect, the sub-pad 756 is adapted to form a radius of curvature dependant upon the pressure developed between the surfaces being polished, polishing material 765, and the sub-pad 756. For example, a lighter pressure

between an optical component being polished, polishing material 765, and the sub-pad 756 provides for a flatter (*i.e.,* smaller) radius of curvature whereas a greater pressure provides for a rounder (*i.e.,* larger) radius of curvature. In another aspect, to provide for a greater polishing pressure to form a desired radius of curvature while decreasing the polishing time required, the sub-pad 756 includes a firmer surface having more flexure resistance thereon. It is contemplated that the compliance and resilience of the sub-pad 756 may be selected to provide any desired radius of curvature, flexure, and processing time.

Component Testing

[0071] Figures 34 and 35 are a simplified plan view and a side view, respectively, of one embodiment of the optical assembly testing stage 111. The optical assembly testing stage 111 is disposed adjacent the optical carrier transportation system 114 to facilitate the automatic testing of a plurality of assembled optical components. The optical assembly testing stage 111 may include a number of different optical component testing tools 800 (one is shown). The optical component carriers 116 move along the optical carrier transportation system 114 and are positioned adjacent the optical component testing tool 800 that includes at least one powered component testing stage 802 interfaced to a optical testing equipment module 812. The powered component testing stage 802 may generally include a test robot 804 that has a test pincher 806 adapted to move one or more of terminated fiber optic assemblies to a processing position. In one aspect, the powered component testing stage 802 includes a component stimulation tool 808 that is adapted to provide power and signals to the components within the optical component carrier 116. The powered component testing stage 802 may also include an optical interface front end 812 adapted to receive an optical component, *e.g.*, a ferrule. In one aspect, the component stimulation tool 808 may be adapted to mate with the optical component carrier 116 such that the stimulation signals and power (*e.g.*, bias) from the component stimulation tool 808 are transmitted to the components within the optical component carrier 116. For example, an attenuation module may be located within the optical component carrier 116. The component stimulation tool 808 provides the electrical power and the signals necessary to operate the attenuation module. The component end of the cable 237 may be inserted into the component interface front

end 812. Test signals from the component interface 812 may then be transmitted to the component testing system 820 for analysis. In another aspect, the testing system 820 is adapted to verify if the optical interface and or optical component is defective. In another aspect, the process controller 118 controls the testing process and equipment.

[0072] Although various embodiments which incorporate the teachings of the invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments within the scope of the invention. For example, it is contemplated that the staged optical component processing system 100 may be configured to simultaneously process a plurality of different types of optical components and components either serially or in parallel. For example, a fiber optic switch including a plurality of pigtail fiber optic cables may be processed simultaneously with a fiber optic amplifier having a single fiber optic pigtail. Therefore, while foregoing is directed to exemplary embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.